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Lightning and th



A tremendous lightning bolt which appeared to impact F ground well to the north. If the strike had occurred over the stainless steel catenary wire (supported by the lightning m hangs suspended over the pad from north to south.

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spheric electricity. The three largest programs have been the Thunderstorm Research International Project (TRIP) conducted in the mid-1970s, the Rocket Triggered Lightning Program (RTLTP) conducted from the mid-1980's until 1992 and the Convection and Precipitation/Electrification (CaPE) program of 1991.

Additionally, three programs using aircraft having electric field measurement capability have been conducted at KSC. The first occurred during the Apollo-Soyuz program to safely enhance launch availability for short-launch-window docking missions. The second was the Airborne Field Mill (ABFM) program to study revising our lightning launch commit criteria to safely relax them based on better understanding of the actual hazards. Finally, NASA's Langley Research Center, Marshall Space Flight Center, KSC, Stanford Research International, Aeromet Incorporated and New Mexico Technological University conducted airborne experiments as part of the RTLTP.

Many investigators from other governmental agencies, leading universities, utilities and international organizations have conducted ground-based and airborne lightning experiments as a part of the KSC program. The French government was a major participant in the RTLTP since it pioneered this type of research along with the United States.

Several other NASA Centers are heavily involved in lightning-related research. NASA Langley scientists have studied aircraft-triggered lightning by flying specially instrumented and weather-hardened aircraft directly through thunderstorms in Virginia and Oklahoma. Much of what we know about this phenomenon was discovered through work with an F-106B fighter airplane. During eight years of research, the airplane was struck by lightning more than 700 times. Nearly all of these strikes were triggered by the aircraft's motion through the intense thunderstorm-electric field rather than as the result of intercepting a natural lightning bolt. The FAA and the Air Force have conducted similar experiments to determine how to better protect aircraft electronics.

Marshall Space Flight Center (MSFC) in conjunction with Langley and KSC has measured electric fields aloft using airborne field mills to assess what conditions pose a threat of triggered lightning during space vehicle launches. Scientists from the University of Arizona, New Mexico Tech and other universities are examining KSC/CCAS

39B have been struck at least five times with a Space Shuttle on the pad – with no damage to any equipment. In 1983, lightning struck the launch pad with the Shuttle on the pad before three of the four launches. To this date, no NASA KSC employee has ever been injured by lightning – due in part to the Lightning Protection Policy. Thanks to the extensive weather and electric field detection systems, no Space Shuttle has ever been endangered during launch, although several launches have been delayed due to reported weather conditions.

The Future of Lightning Prediction, Detection and Research

As society becomes more dependent on computers and other electronic devices, more effective ways must be developed to protect this equipment against high-voltage shock. Future aircraft constructed of non-conductive composite materials, that "fly by wire" or by computer command instead of manual hydraulic systems, will need advanced protection systems. As the global population expands, the increase of people and property calls for improved lightning prediction and detection through advanced weather equipment and methods. As one of the more lightning-sensitive residents of the "lightning capital of the United States," KSC will continue to apply its technical expertise to support these efforts.

primary method of reducing lightning risk is by scheduling rollout during periods of very low lightning probability – typically in the late night and early morning hours.

Launch Pad Detection Systems

A lightning measuring system is located at the launch pads so that any electrical activity in the immediate area can be continually observed, recorded and assessed. Data gathered by its sensors and cameras is sent directly to the Launch Control Center so that NASA personnel can determine when it is safe to launch the spaceplane.

One of the monitors closest to the Shuttle is the Catenary Wire Lightning Instrumentation System (CWLIS). This system senses lightning currents in the wire and evaluates them to see what potential they may have for causing damage to sensitive electrical equipment. The CWLIS current sensors are located at each end of the catenary wire and detect and record lightning strikes to provide potential damage assessment data for the CWLIS system.

Another launch pad monitoring system, the Lightning Induced Voltage Instrumentation System (LIVIS), detects and records any transient electrical impulses that might occur in Space Shuttle electronic systems or on the vehicle's skin. LIVIS is installed in the MLP and monitors conditions while the Shuttle is on the way to the launch pad via the crawlerway and at the pad itself.

Data recorded by both the CWLIS and LIVIS systems are compiled and sent to the Launch Control Center through the computers of the Lightning and Transients Monitoring System (LATMOS).

Visual detection of lightning activity is also essential. A network of video cameras positioned to observe the Fixed Service Structure's lightning mast and the top of the Shuttle's External Tank are linked to television monitors in the Launch Control Center. Any lightning flashes can be seen on the screen and recorded for later analysis.

Does It all Work?

The elaborate lightning detection and protection systems at KSC have proven their worth the hard way. The lightning masts at Launch Pads 39A and

ground-based field mill data for additional clues concerning what conditions are safe and which are hazardous in order to design launch rules which will provide maximum opportunity to launch without compromising safety.

MSFC has investigated thunderstorms by overflying them with U-2 aircraft, and is also investigating lightning by satellite. Its Optical Transient Detector (OTD) is able to detect and locate lightning from orbit over large regions of the globe. A highly compact combination of optical and electronic elements, it represents a major advance over previous technology in that it gathers lightning data in day time as well as night. OTD and its follow-on, the Lightning Mapper, will enable more accurate estimates of the energy and current associated with the global electrical circuit.

Lightning — One of Nature's Most Violent Forces

At any instant, there are more than 2,000 thunderstorms taking place throughout the world. These storms combine to produce about 100 lightning flashes per second, each one with a potential of up to a billion volts, currents ranging up to 200,000 amperes, and temperatures of over 54,000 degrees Fahrenheit. A moderate-sized thunderstorm at its peak can generate several hundred megawatts of electrical power, equivalent to the output of a small nuclear power plant. With so much energy being released, there is little wonder that lightning has considerable potential to cause damage.

Lightning On Other Planets

These giant electric sparks are not unique to Earth. Among the mystifying and gargantuan storms that rage throughout Jupiter's atmosphere, cameras on NASA's Voyager I planetary explorer spacecraft found one familiar phenomenon—lightning. Both Voyager I and II detected electrical signals from Jupiter characteristic of lightning. This discovery was the first hard evidence that such violent electrical discharges take place on other planets. The Galileo spacecraft also photographed what appear to be visible lightning flashes in Jupiter's atmosphere. Detection of electrostatic discharges on Saturn and Uranus by Voyager 2, along with radio signals associated with lightning picked up by the Pioneer Venus orbiter and Russian Venera probe, may indicate that lightning is commonplace in our solar system.

ops, better ways to predict its occurrence, and the means to reduce damage when it does strike. To attempt to predict where the next strikes will occur, a National Lightning Detection Network (NLDN) has been established across the USA. The NLDN plots the strike location of each cloud-to-ground flash. KSC has developed a new precision three-dimensional Lightning Detection and Ranging (LDAR) system which is being commercialized under a Space Act agreement between NASA and Global Atmospheric, Inc. LDAR allows the forecaster to view the height and horizontal extent of each lightning flash and not just the point-of-ground contact. Unlike the NLDN, the LDAR can also detect in-cloud and cloud-to-cloud flashes. Soon, satellites that observe the whole planet will supplement ground detectors to increase coverage of thunderstorm activity. Meteorologists can use this data to alert people in potential strike areas. The more accurate the prediction of where and when lightning will occur, the better chance there is of reducing or eliminating the damage it causes.

Ground Equipment Needs Most Protection

Since lightning tends to strike the highest local point, special care must be taken to protect tall structures from direct strikes. These structures are often power lines, microwave relay towers used in telephone communication, or buildings filled with sensitive electrical equipment. Without protection, a lightning strike can cause power line surges and arcing, electrical fires and electrical or structural damage.

The National Fire Code standards for lightning protection (NFPA-780) for structures call for a pathway, or conductor, that will safely redirect a lightning bolt's electrical energy to the ground. Additional protection is provided by circuit breakers, fuses and electrical surge arrestors. Sometimes even this equipment is not sufficient to prevent damage. Studies, including results from the RTLP, have shown that lightning strikes result in rapid current surges (reaching an initial peak within a millionth of a second) with such high peak current (over 100,000 amperes) that conventional protection methods are unable to save complex electronic systems from damage. Utilities and high-technology industries, among others, are investigating ways to better protect vital electrical equipment.

LDAR detects and locates lightning in three dimensions using a "time of arrival" computation on signals received at seven antennas. Each part of the stepped leader of lightning sends out pulses which LDAR receives at a frequency of 66 MHz (equal to TV channel 3). By knowing the speed of light and the locations of all of the antennas, the position of individual steps of a leader can be calculated to within 100-meter accuracy in three dimensions. LDAR provides between 1 and 1,500 points per flash. This is the only system currently able to provide detailed information on the vertical and horizontal extent of a lightning flash rather than just the location of its ground strike. LDAR detects all lightning including cloud-to-cloud and in-cloud as well as cloud-to-ground.

The LLP detects, locates and characterizes cloud-to-ground lightning within approximately 60 miles of the RWO. Electromagnetic radiation emitted from lightning is first detected by the system's three direction finder antennas located at Melbourne, Orlando, and in the northern area of KSC. Lightning positions are computed using triangulation from two of the sites and relayed to a color display video screen in the RWO. Once lightning-producing cells are identified and located, it becomes easier for the forecaster to predict just where the next lightning bolts will hit.

KSC's Lightning Policy

KSC pioneered a two-phase lightning warning policy. In Phase I, an Advisory is issued that lightning is forecast within five miles of the designated site within 30 minutes of the effective time of the Advisory. The 30-minute warning gives personnel in unprotected areas time to get to protective shelter and gives personnel working on lightning sensitive tasks time to secure operations in a safe and orderly manner. A Phase II Warning is issued when lightning is imminent or occurring within five miles of the designated site. All lightning-sensitive operations are terminated until the Phase II Warning is lifted. This two-phase policy provides adequate lead time for sensitive operations without shutting down less sensitive operations until the hazard becomes immediate.

The Lightning Policy is defined by the KSC Lightning Safety Assessment Committee. This group is also responsible for seeing that all structures at KSC, as well as the Space Shuttle, are adequately

Lightning Detection Systems – The Launch Pad Lightning Warning System (LPLWS), Lightning Detection and Ranging (LDAR) system and the LLP Lightning Detection System provide data directly to the Range Weather Operations on atmospheric electrical activity. These systems, along with weather radar, are the primary Air Force thunderstorm surveillance tools for evaluating weather conditions that lead to the issuance of lightning warnings.

The LPLWS is made up of 31 electric-field mills uniformly distributed throughout KSC and Cape Canaveral. They serve as an early warning system for electrical charges building aloft or approaching as part of a storm system. These instruments are ground-level electric field strength monitors. Information from the LPLWS gives forecasters information on trends in electric field potential and the locations of highly charged clouds capable of supporting natural or triggered lightning. The data are valuable in detecting early storm electrification and the threat of triggered lightning for launch vehicles.



This is one of the 31 electric field mills that comprise the Launch Pad Lightning Warning system. They are called mills because they have a rotating four-bladed shield much like arms of a wind mill. The shield contained in the bottom of the round housing alternately exposes and covers metal sensing plates resulting in an alternating current proportional to the atmospheric electric field.

Better Protection Begins with Better Knowledge of Lightning

Although lightning has been known to be a discharge of electrical energy since Ben Franklin's kite-flying days, the way electrical charges build up and discharge in clouds is still not fully understood. Researchers at Kennedy Space Center and other facilities throughout the world have attempted to answer these questions so that improved means to detect and measure the charges can be developed.

What is known is that a lightning bolt is the transfer of a positive or a negative electrical charge from one region of a cloud to another, between clouds, or between a cloud and the ground. For such a transfer to take place, the two types of charges must be separated so that the cloud is electrified. Exactly how the charges become separated and where in the cloud they are located are still not completely clear.

Is a Thundercloud Like a Generator?

However the details may turn out, it is well understood that thunderstorms separate electrical charge. Usually, a positive charge is pumped aloft while a negative charge accumulates near the lower-middle part of the storm. A small amount of positive charge may collect near the base of the storm cloud. It takes energy to separate the charge, and this energy comes from the rapidly rising air currents in the storm. Thus, like a generator, a thunderstorm converts mechanical energy to electrical energy.

Convection and the Formation of Thunderstorms

A thunderstorm is a natural heat engine. On a typical summer day over Florida, the air is loaded with moisture and the land surface is hot. As the air near the surface is heated by the land, it expands, becomes less dense (hence lighter) and begins to rise. As it rises, it expands further, this time due to the lower pressure higher in the atmosphere rather than due to heating. In fact, as the air expands in the lower pressure, it cools because its internal energy is spread out over a larger volume. When moist air cools enough, it can no longer hold all the water it contained when it was warm. If it were on the ground, dew and fog

Most lightning occurs within or between clouds. The destructive cloud-to-ground lightning bolt occurs much less frequently and can carry either a positive or a negative charge. Of the two, negative lightning is the most common type (about 90 percent). The process involved in generating a lightning stroke explains why lightning usually seeks out and strikes the highest point on the surface.

First, a negatively charged, stepped leader from the cloud approaches the ground. During the approach, the leader's tip causes electric fields on the ground to increase in strength. Positive ions gather around pointed objects as small as pine needles and grass blades and then flow in streams towards the leader. When they get close enough, closure of the cloud-ground circuit takes place and the leader is neutralized. Now a much more powerful return stroke flows through the



Cloud strike is caught in the act as it zaps a tree.

ionized channel from the ground to the cloud. The grounded object serves as the focal point of the positive ion flow. That object, such as from tree to golfer with an upraised club, is considered “struck” by lightning. The whole process, from leader approach to discharge, takes place in less than a second.

The return stroke is easily visible to the human eye, with the brightness of more than 100 million light bulbs. Actually, this bolt may have traveled back and forth between the cloud and the ground more than a dozen times – all in less than a second. The entire event is called a lightning flash.

Positive lightning carries a positive charge to the ground. It makes up less than 10 percent of a storm's lightning strikes and typically takes place at the end of a storm. However, the positive lightning strike has the potential to cause more damage. It generates current levels up to twice as high and of longer duration than those produced by a negative bolt. It's the long-duration, or “continuing current” components, of lightning that causes heating, burning and metal punctures. For that reason, scientists are especially interested in developing ways to detect the areas of a thunderstorm that develop positive bolts.

Triggered Lightning — A Bolt from the Gray?

The phrase “a bolt from the blue” originated from observations of a seemingly inexplicable phenomenon – a flash of lightning on a day without a storm cloud nearby. This event would be startling under any circumstances, but imagine the shock of seeing such a bolt strike the 363-foot-high Apollo 12/Saturn V rocket while it was more than a mile above KSC. Perhaps being in an airliner while it was “zapped” by lightning at 20,000 feet would be more of a scare, though. While not really bolts from the “blue,” because they occur inside of clouds, they occur in clouds which otherwise do not contain lightning—which are not “storm clouds.”

Why are rockets and airplanes struck in these circumstances? It was first thought that they just “got in the way” of a lightning bolt jumping from a positive- to a negative-charged area of a thundercloud. Later research provided evidence that the buildup of strong electric fields at certain points of the aircraft were the culprit.